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THE SIGNIFICANCE OF PHONOCARDIOGRAPHY IN CLINICAL PRACTICE

-USSR-

[Following is the translation of an article entitled "Znachenije fonokardiografii v klinicheskoy praktike" (English version above) by A.I. Koblents-Mishke (Leningrad) of the Chair of Propedeutics of Internal Diseases (Chief, Active Member of the Academy of Medical Sciences USSR, Prof N.N. Savitskiy) of the Order of Lenin Military Medical Academy imeni S.M. Kirov, in Klinicheskaya Meditsina (Clinical Medicine), Vol XXXVIII, No 5, Moscow, 1960, pages 139-145.]

Phonocardiography -- a graphic recording of the sound vibrations arising from the working of the heart -- was first done 65 years ago (Einthoven and Geluck). Since then a great deal of work has been done to perfect the method. Present-day phonocardiography differs essentially from that known to clinicians until a relatively short time ago.

Despite the fact that the possibilities of phonocardiograph are far from having been fully discovered, it has already become a solid part of clinical practice and is widely applied in a number of foreign countries (Germany, US, Sweden and others). A number of works have been published (G.I. Gel'shteyn and L. M. Fitileva, V.I. Maslyuk, V.V. Solov'yev, L.M. Fitileva and others) on clinical phonocardiography by [Soviet] clinics equipped with modern apparatus.

[Soviet] phonocardiographs are now being developed (A.M. Rybakov) and turned out in series, creating conditions for the spread of the method in the USSR. An indispensable condition for its proper application is a clear idea of the characteristics and possibilities of modern phonocardiography.

Phonocardiography records the sound vibrations, i.e. those vibrations which correspond to the area of auditory perception. The method is based on 140 years of experience in auscultation. Thus, by definition, as well as by origin and purpose, phonocardiography is inseparably connected with auscultation. A comparison of the possibilities of phonocardiography with those of auscultation must be made by all the basic parameters characterizing the sounds of the heart. We must discuss the possibilities of phonocardiography and auscultation in the perception of this or that sound (sensitivity) and in the evaluation of their force, frequency composition and time relationships. Before

doing so, it is necessary to set forth briefly the basic principles of modern phonocardiography (for further details see A.I. Koblents-Mishke, Litkem and Trendelenburg).

In modern phonocardiographs, the microphone converts the mechanical sound vibrations into electric vibrations; the latter are amplified and recorded on a moving tape.

The sound energy (intensity, force) defines the range of the vibrations; the amplitude of the serrations of the phonocardiogram is proportional to the sound pressure and consequently to the square root of the force of the sound. As regards the pitch, it can be established from the number of vibrations recorded per unit of time. (Fig. 1). [Illustrations are appended, pages 12-15.]

In the working of the heart, vibrations of different frequency and amplitude are superimposed upon one another. These are, firstly, the vibrations of subsonic frequency, communicated to the thorax by the heart as it changes its shape and volume, and the vibrations due to the displacement of the mass of the blood and of the heart; secondly, the more frequent vibrations (tens and hundreds of vibrations per second) perceptible as heart sounds -- "tones" and "noises." From the physical viewpoint, the so-called tones of the heart are also sounds inasmuch as they are formed by irregular vibrations.

The tones of the heart are represented by frequencies which in the main do not exceed 150-200 hertz (vibrations per second). In pathological cases, components of greater frequency may take a considerable part in the formation of heart tones. Sounds of the heart are formed by vibrations of higher frequency, reaching 400-1,000 vibrations per second or more for many categories of noises. The distribution of the energy of heart sounds by frequencies is very uneven in various cases, but in general the energy (intensity) diminishes sharply with increase in the frequency of the vibrations. The intensity of vibrations of subsonic frequency is greater than that of vibrations corresponding to tones. The intensity of tones for the most part considerably exceeds that of sounds.

The sensitivity of man's organ of hearing is not the same at different frequencies. It is known that vibrations with a frequency lower than 16-20 hertz are not perceived at all as sounds. In the frequency band in which the heart sounds lie, the sensitivity of hearing grows with increase in the pitch. Hence, in auscultation both noises and heart tones are perceived equally well, though the intensity of noises is considerably lower than

the intensity of tones.

With equal amplification of all the frequency components, the thorax vibrations of subsonic frequency are recorded in the form of waves of great amplitude. The vibrations representing the heart tones form poorly distinguishable serrations in this curve. The noises, as a rule, are not recorded, since their energy is very small. The curve obtained is called a linear phonocardiogram or vibrogram. It does not differ essentially from a cardiogram or precordial ballistocardiogram. Such a curve gives no idea of the heart sounds.

In order to record the heart sounds with sufficient thoroughness, it is necessary to lower the sensitivity of the apparatus to low-frequency components or, which is the same, to amplify the high-frequency components selectively. In modern apparatus, this is done with the aid of so-called electric filters. Depending upon the degree to which the sensitivity to low-frequency components is reduced, one distinguishes phonocardiograms "with a hearing characterization" as low-frequency or high-frequency.

If the sensitivity to low-frequency components is lowered to approximately the same extent as is the case with respect to the threshold of the sensitivity of the hearing, a so-called phonocardiogram with a hearing characterization (Trendelenburg) as "auscultative" or logarithmic" (Rappoport and Sprague) is recorded. Such a curve permits one to obtain the most complete idea of the auscultative picture.

In recording low-frequency phonocardiograms (including the "stethoscopic", according to Rappoport and Sprague, and the low-frequency and first medium-frequency one, according to Maass and Weber), the sensitivity to low-frequency components, though lowered, is reduced to a lesser extent than is the case in recording a phonocardiogram "with hearing characterization." This permits one to record poorly audible low-frequency elements, including tones III and IV, and to some extent also the vibrations of subsonic frequency.

In recent years there has been an ever wider distribution of high-frequency phonocardiograms (Maass, Mannheimer) with a more considerable suppression of low-frequency components than for the "auscultative" characterization. Such recording has proved very useful in clinical practice, since it permits one to detect high-frequency elements important for diagnosis (diastolic noise in aortal failure, systolic noise in mitral failure, clicking from the opening of the mitral valve, and so forth) and to differentiate them from similar non-patho-

logical elements (accidental systolic noise, tone III), in the formation of which high-frequency components do not participate (Schlitter and Scholmerich, Wittig). By employing systems of filters permitting the recording of heart sounds in different frequency bands, it is possible to detect more fully the elements of different pitch and make a rough frequency analysis of heart sounds (Fig. 2).

The idea exists that the task of phonocardiography is only a matter of recording weak, auscultatively imperceptible sounds. Actually, its main object is to obtain additional information about sounds the presence of which has already been established by auscultation. The sensitivity of the phonocardiographs far from surpasses in every respect the sensitivity of the human ear; in the area of frequencies corresponding to the higher heart sounds (of the order of 300-1,000 hertz), the latter is very great. Present-day apparatus do not always record sufficiently well certain high-frequency heart noises that are weak, but still distinctly audible to most physicians.

In the area of lower frequencies, the sensitivity of the apparatus, though not too high, nevertheless exceeded that of the human ear already in the first years of existence of phonocardiography. For this reason, many researches (T.A. Teslya-Tsvyakh, Rosa) have placed great hopes in the study of low-frequency phonocardiograms, the significance of which should be discussed in more detail.

In the interpretation of the physiological and diagnostic significance of the low-frequency elements of the phonocardiogram there are considerable difficulties. In evaluating these elements one must not rely on auscultation experience. It is by no means always possible, for example, to identify low-frequency vibrations, recorded before the first tone, with presystolic noise (see Fig. 2, B).

The interpretation of low-frequency elements of a phonocardiogram is similar to that of the elements of a cardiogram. In the past, thorough study of the cardiogram has afforded valuable data on the dynamics of cardiac activity and made it possible to study the duration of the phases of the heart cycle. But it was then realized that the cardiogram cannot be used in every-day diagnostic work. The form of the curve is determined by too great a number of individual factors, the recognition of the identification points on it is often very uncertain, and not infrequently downright impossible. One also encounters difficulties of this sort in reading a low-frequency phonocardiogram.

I have been able to apply the results of the study of the low-frequency elements of the phonocardiogram to the study of the dynamics of cardiac activity and made it possible to study the duration of the phases of the heart cycle. But it was then realized that the cardiogram cannot be used in every-day diagnostic work. The form of the curve is determined by too great a number of individual factors, the recognition of the identification points on it is often very uncertain, and not infrequently downright impossible. One also encounters difficulties of this sort in reading a low-frequency phonocardiogram.

In clinical practice, the low-frequency phonocardiogram finds only limited application. But it facilitates the reading of high-frequency phonocardiograms if these do not permit the detection of certain heart tones and their separate components (particularly, when the tones do not stand out against the background of noises).

The sensitivity of the phonocardiogram can surpass that of auscultation not only in the area of low-frequency vibrations. In auscultation, the possibilities of perceiving heart sounds are determined not only by their force and frequency compositions, but also by a number of other factors. Thus, for example, unprotracted sounds are perceived more poorly. Sounds separated from one another by a short interval of time may be perceived as a single sound. Of great significance is the masking effect. A stronger sound may interfere with the perception of a following weak sound (for example, strong tone II may interfere with the perception of a weak prodiastolic noise). In all such cases phonocardiography may detect elements not perceptible auscultatively.

Of no less significance in clinical practice than the perception of weak sounds is the evaluation of the intensity of a sound. In auscultation, the evaluation is rough and uncertain and does not satisfy the requirements of clinical practice, especially as regards dynamic observation. With regard to weak and low sounds of the heart, the difference in intensity can be established only when one of two successively perceived sounds is not less than $1\frac{1}{2}$ - 3 times more intense than the other. In listening to sounds not following directly upon one another, the possibilities are still less.

Phonocardiography permits a quantitative evaluation of the force of the heart sound with a precision not less than $\pm 5\%$. However, as will be discussed below, these possibilities are not used to the full.

The frequency composition of heart sounds, which determines their pitch, height and timbre, is perceived very well in auscultation. A physician, for example, easily recognizes the harsh systolic noise of aortal stenosis; the characteristic frequency composition of this noise permits one to distinguish it from a systolic noise of other origin. But the evaluation of the frequency composition of heart sounds is subjective in character, and the respective definitions ("harsh", "soft", etc.) are not sufficiently objective.

Phonocardiography is inferior to auscultation in the precision of evaluation of the frequency composition of sounds. In particular, it does not detect very weak

high frequency components which place their imprint on the auscultatively perceptible timbre. Frequency analysis of phonocardiograms (the special mathematical processing of curves) is very laborious and goes beyond the framework of phonocardiography proper. Neither this analysis nor research with the aid of special frequency analyzers have yet revealed the physical nature of certain timbre characteristics of heart sounds, though these characteristics are perceived auscultatively and permit the clinician to draw important conclusions for diagnosis.

It has been said above that the use of several filters with different frequency characteristics permits one to make a rough frequency analysis.

If, for example, a protodiastolic extra tone is recorded only on a low-frequency phonocardiogram, this means that high-frequency components take no part in its formation, which is more characteristic of physiological tone III (see Fig. 2,B). But if such an extra tone is registered principally in a high-frequency recording, this bespeaks a high-frequency composition of the sound, which is more characteristic (Schlitter and Scholmerich) of the click made by the opening of the mitral valve (mitral stenosis, Fig. 2, C).

It is necessary however, to bear in mind that the filters used in modern phonocardiographs do not strain out abruptly the low-frequency components, but only more or less gradually reduce the sensitivity to them. Hence, the more intense low-frequency vibrations can also be recorded on a high-frequency phonocardiogram, i.e. one intended for the registration of high-frequency elements. Similarly, the high-frequency components, if their intensity is not as small as usual, may appear on the low-frequency phonocardiogram.

This circumstance is not infrequently underestimated. From the fact, for example, that tone I is recorded on a high-frequency phonocardiogram, the insufficiently based conclusion is drawn that components whose frequency exceeds 250 hertz (Gaderman and Ziegel) are present in that tone. Intensive vibrations whose low-frequency character is satisfied by the curveform are erroneously assessed as high-frequency phonocardiogram (Luisada and others).

The possibilities of phonocardiograph in the evaluation of the force and frequency composition of heart sounds are restricted by insufficient standardization of the apparatus. One of two phonocardiographs of the same type may prove to be 2-3 times more sensitive than the other at a certain frequency while having the same sensitivity at another frequency. At the present

level of technology, such a discrepancy between the parameters of apparatus is inevitable (Holldack and Wolf).

The conditions of fixation of the microphone, particularly the pressure exerted by it on the integuments of the thorax, affect the sensitivity of the microphone and the conduction of the sounds to the receiving element of the microphone. This limits the possibilities of comparing the force and the frequency component of sounds even when working with one and the same apparatus (A.M. Rybakov, Rappoport and Sprague).

All of the above does not mean, however, that phonocardiography does not permit one to evaluate the pitch, height and force of sound. Such an evaluation is possible and fully justified. It will in any case be more certain and, with respect to the force of the sound, more precise than the evaluation allowed by auscultation. It is only necessary to have an idea of the precision limits of the method and to remember the possible sources of error. In particular, insignificant changes in the amplitude of recording can be gauged only when the necessary conditions are observed (working with one and the same apparatus under the same conditions of placement of the microphone).

The greatest advantages over auscultation are afforded by phonocardiography in the evaluation of the time relationships. These advantages are very important, since in clinical practice the greatest significance attaches to time relationships, the assignment of heart sounds to this or that moment during the heart cycle (S.F. Oleynik).

In auscultation, the length of the heart sounds and intervals between them is determined very imprecisely. Errors are inevitable even in determining the sequence of two sounds, which have, for example, the result that a short presystolic noise is mistaken for a systolic one (Holldack). Errors of this sort in the sequence of two sounds are impossible in phonocardiography. The position of the elements of a phonocardiogram is determined with a precision of 0.005 second (Mannheimer). Within these limits, the precision of measurement of time relationships does not depend upon the type of apparatus, the composition of the heart sounds or the method of fixing the microphone. This protects the interests of dynamic observation and facilitates a comparison of the results obtained by different researchers.

The length and character of the swelling and fading of the noises, the position in time of their maximum intensity are well revealed in the phonocardiogram. In auscultation, such an evaluation can only be made very

approximately and only when there are considerable changes in the volume of the sound.

Phonocardiography permits one to compare in time the heart sounds with other manifestations of its activity. Parallel recording of a phonocardiogram, an electrocardiogram, a sphygmogram and other curves has acquired great significance both in physiological research and in clinical practice (Nazzi and co-authors, Wells, Fig. 3).

Thus, for example, the length of the period of transformation is determined by the interval from the beginning of the QRS complex of the electrocardiogram to the beginning of the principal component of tone I on the phonocardiogram. A lengthening of this interval Q-I is characteristic of mitral stenosis.

In evaluating the possibilities of the phonocardiogram and comparing them with the possibilities of auscultation one must bear in mind one of the main merits of the phonocardiographic method, its objectivity. In auscultation, in listening to the heart sounds recorded on a magnetic tape, or in observing the corresponding images on the oscilloscope screen, one has to do with fleeting impressions that often escape attention. The phonocardiogram places at the physician's disposal clear data of a documentary character. Even in investigating the frequency composition of a sound, where phonocardiography is inferior to auscultation in precision of evaluation, the objective character of the method makes it more reliable, and the rough evaluation of the frequency composition permitted by present day phonocardiography proves very useful. Understandable is the interest shown in phonocardiography in those cases where an especially responsible decision has to be made -- when it is, for example, a matter of operating on the heart or deciding expert questions. Phonocardiography brings great benefit in the process of teaching auscultation of the heart.

The significance of phonocardiography in clinical practice is determined not only by its fundamental possibilities in the evaluation of heart sounds, but also by the practically realizable completeness of investigation.

In a comparatively short space of time the physician is able to listen to the heart at standard and supplementary points, in different phases of respiration, with the patient in different positions, at rest and after effort. He adapts himself to the intensity and pitch, height of the sounds investigated, and detaches himself from extraneous noises. Phonocardiographic research, being more labor-consuming than auscultation, cannot lay

claim to such completeness. In the course of phonocardiographic research, the degree of amplification in the various frequency ranges and the different conditions of recording are selected anew in each separate case. The fixing of the microphone also takes some time. Frequently one has to change the conditions and make a second recording. In order to obtain the fullest information, it is necessary to work out a rational plan of phonocardiographic research. Here it is necessary to take into account the peculiarities of the method. The research plan must make allowance for the auscultation data. These data permit one to set limited tasks and plan the most suitable conditions of registration (points of fixing the microphone, position of the patient, phase of respiration, etc.).

In examining phonocardiograms, one can convince oneself in a particularly graphic manner that heart sounds are often extremely labile. Elements important for diagnosis may appear only under certain conditions, and their characteristic peculiarities may manifest themselves with equal inconstancy. Hence, the main attention should be paid to methods permitting the detection of such elements and their peculiarities. Here belongs recording with and without retention of the breath, with straining, with the patient lying on his left side, etc. (A.I. Koblents-Mishke, Calo). At the same time, the research program may be shortened by the fact that the origin of sounds (noises, components of tone II, etc.) can be determined from their position in time and their characteristic graphic configuration independently of the location of the microphone. In most cases it is not at all obligatory to take phonocardiograms at each of the standard auscultation points.

The absence of any auscultatively detected signs on the phonocardiogram does not by any means always give evidence of error in auscultation. On the contrary, the auscultation data must be used to check the quality and completeness of the phonocardiographic investigation. In a number of cases only a second investigation with changed conditions of recording will permit precise information to be obtained.

The possibilities of wide clinical application of phonocardiography are largely determined by the perfection of the apparatus. Multi-channel apparatus with direct visible recording will considerably reduce the amount of work and make the method more accessible.

All the above permits us to come to certain conclusions.

Phonocardiography is a valuable method of investigating the action of the heart, being developed on the basis of the achievements of auscultation and in many ways

supplementing it. For its correct use it is necessary to have a clear idea of the method's possibilities. Phonocardiography is not designed for a precise measurement of the force, and especially the frequency composition, of heart sounds. But it does permit one to make an objective evaluation of these indices, which in many ways excels auscultative evaluation. The greatest advantages of phonocardiography are in the field of investigating time relationships, where it reveals new possibilities, rendering accessible the comparison in time of the sounds of the heart with the other manifestations of the heart's activity.

Phonocardiography cannot replace auscultation. Indeed, auscultation of the heart is an indispensable element of all phonocardiographic research. The latter in turn permits one to obtain valuable information on the sounds of the heart, and to characterize supplementarily those sounds which in most cases have already been detected by auscultation. Much of this supplementary information cannot be obtained auscultatively, which fact permits us to evaluate phonocardiography as an independent method of investigation differing from auscultation but again not replacing it.

The present day apparatus, as a rule, permit one to record all the elements perceived auscultatively. It places valuable information at the disposal of the researcher. At present, by no means all of this information can be used, and the significance of many details being revealed by means of phonocardiography has still not been ascertained. The accumulation of experience in the application of phonocardiography and the broadening of our notions about the physiology and pathology of the heart's activity will expand the volume of useful information placed at the clinician's disposal by the phonocardiographic method of research.

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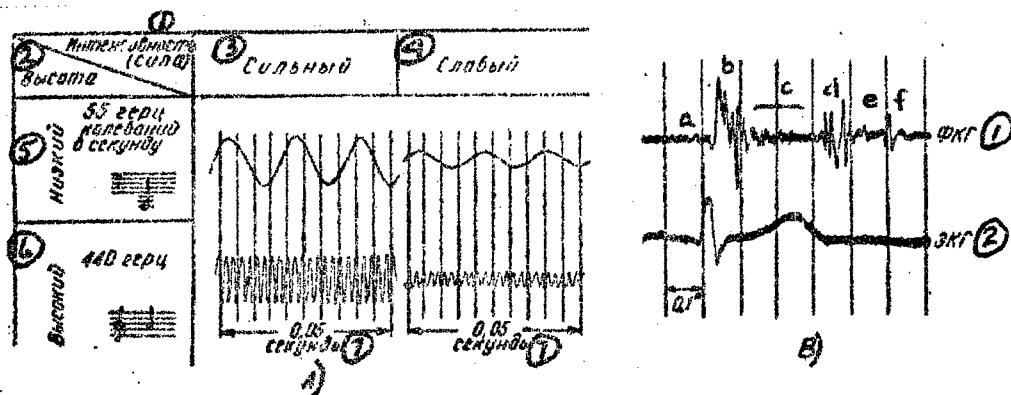


Figure 1. Characterization of Sound (Force and Pitch)
in Graphic Representation

A -- Pure tones; B -- Heart sounds (phonocardiogram) -- "auscultative" frequency characterization; electrocardiogram below:
a -- Non-intensive low-frequency vibrations (of the order of 50 hertz) before tone I; b -- Tone I is represented by high frequency vibrations of considerable intensity; c -- Systolic noise; high-frequency vibrations the intensity of which is perceptibly lower than that of the vibrations representing tone I; gradual diminution of intensity toward end of systole; d and e -- tone II; at beginning, d -- high frequency vibrations of considerable intensity, then e -- less intensive vibrations of lower frequency; f -- tone III, represented by low-frequency vibrations the intensity of which considerably exceeds that of the vibrations before tone I (a). It may be seen that the heart sounds ("tones" and "noises") are represented by irregular vibrations, i.e., from the physical viewpoint they are noises.

Legend to superimposed numbers: Part A: 1) Intensity (force) ; 2) 3) Strong; 4) Weak; 5) Low: 55 hertz of vibrations per second; 6) High: 440 hertz; 7) 0.005 second.

Part B: 1) FKG; 2) DKG.

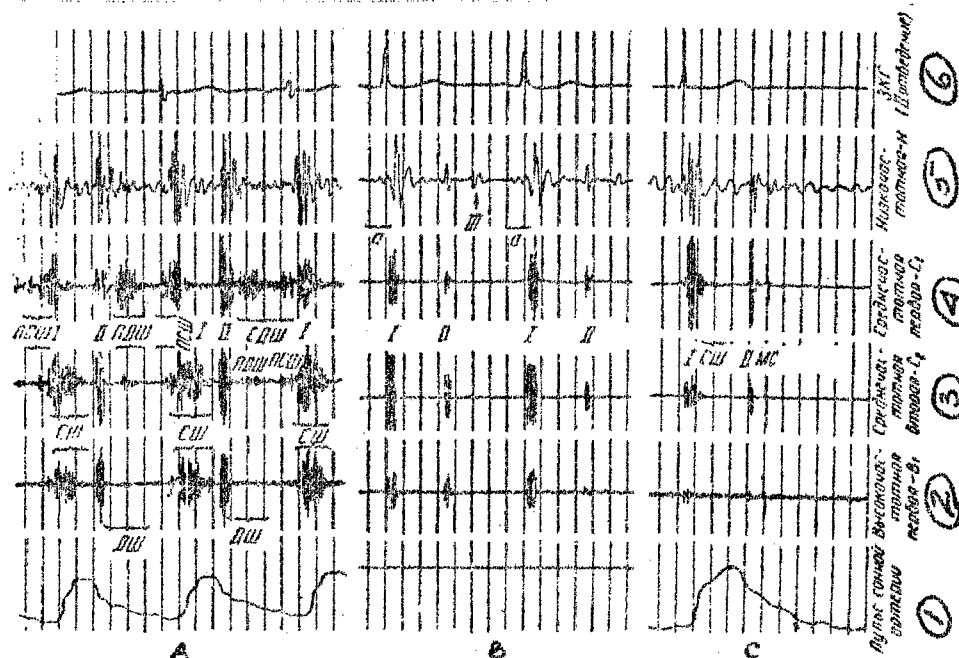


Figure 2. Phonocardiogram Taken with Four Frequency Characterizations According to Maass and Weber (Hellige "Multi-scriptor" apparatus)

Part A: High frequency recording permits clear registration of high-frequency systolic noise (SN) and less distinct registration of high frequency "vascular" diastolic noise (DN) -- due to aortal or pulmonary failure. Diastolic noises of mitral stenosis -- a protodiastolic noise (PDN), separated from tone II by a short interval, a presystolic noise (PSN) and a saddle-shaped diastolic noise (SDN), formed by their fusion -- are better represented in low-frequency (medium frequency) phonocardiograms. Only a low frequency phonocardiogram permits the first tone (I) to be distinctly detected against the background of presystolic and systolic noise; II -- second tone.

Part B: I -- first tone; II -- second tone; III -- low-frequency third tone, represented in the low-frequency phonocardiogram;

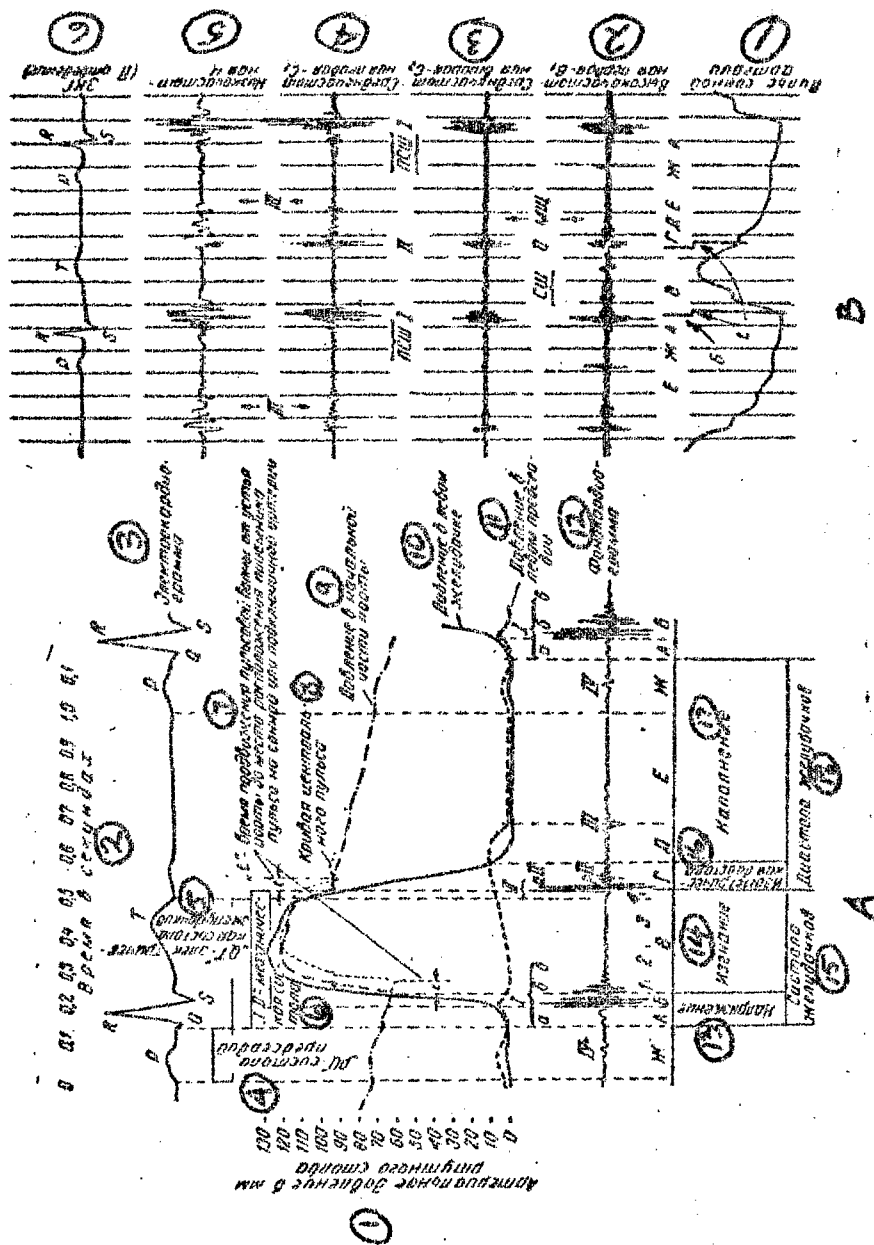


Figure 3. Part A: Elements of Phonocardiogram and Division of Heart Cycle into Phases. Elements of phonocardiogram. I -- first tone: a -- initial vibrations; b -- main vibrations; c -- concluding vibrations. II -- second tone: all -- aortal component; pii -- pulmonary [CONTINUED]

[Figure 3. CONTINUED]

component. III -- third tone. IV -- fourth (auricular) tone. Division of heart cycle into phases. Systole of ventricles: A -- time of transformation (QT); form of ventricle approaches spherical; closed mitral valve bends into the auricle cavity; B -- time of growth of intra-ventricular pressure; C -- period of expulsion. Diastole of ventricles: D -- isometric relaxation of ventricles; E -- rapid filling of ventricles; F -- slow filling (diastasis); G -- systole of auricles ("PQ").

Part B: Combined Mitral Defect. Division into phases, as in Fig. 3A. Other designations as in Fig. 2.

Legend to Superimposed Numbers: Part A: 1) Arterial pressure in mm of mercury; 2) time in seconds; 3) Electrocardiogram; 4) "PQ" systole of auricles; 5) "QT" electric systole of ventricles; 6) "I-II" metallic systole; 7) Time of advance of pulse wave from mouth of aorta to location of pulse receiver on carotid or subclavian artery; 8) Curve of central pulse; 9) Pressure in initial part of aorta; 10) Pressure in left ventricle; 11) Pressure in left auricle; 12) Phonocardiogram; 13) Tension; 14) Expulsion; 15) Systole of ventricles; 16) Isometric diastole; 17) Filling; 18) Diastole of ventricles.

Part B: Pulse of carotid artery; 2) First high-frequency; 3) Second medium-frequency; 4) First medium-frequency; 5) Low-frequency; 6) EKG (Discharge II).